Design of Service Model & System Architecture for Maintenance Support System based on PHM

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ABSTRACT

Led by certain European countries, rolling stock (railway car) maintenance technology is undergoing a paradigm shift from preventive maintenance based on the inspection period to predictive maintenance in a bid to reduce damages to railroad components that cause interruptions to railroad operation and incur unnecessary maintenance costs. This has led to increasing demand for fault diagnosis and remaining- useful-life-prognosis technologies in order to simultaneously satisfy the need for greater reliability and lower maintenance costs to cope with faster systems. This study aimed to design the functions and architecture of a rolling stock maintenance support system that analyzes the status data collected from sensors installed at onboard and wayside in order to automatically evaluate and prognosticate the likelihood of parts failures, so as to manage railroad car parts more efficiently.

1. INTRODUCTION

Although the KTX (Korea Train Express) has been in operation for some time in Korea, the progress of operation and maintenance technology has been slower than that achieved in other leading countries, and many tasks currently have to be conducted manually in the railroad car management and operation system. A lack of original technology and inadequate technology transfer, a shortage of studies related to railroad maintenance systems, and dependence on foreign technologies in Korea are also affecting the business of Korail, which operates the railroads in Korea. Therefore, it is necessary to strengthen Korea's status as an exporter of railroad operation and maintenance technologies by improving the operation of domestic railroads and the capabilities of the railroad industry, and by eliminating inefficiencies in rolling stock maintenance technology and securing the operating and maintenance technology, in order to improve productivity.

The technologies developed for rolling stock maintenance can reduce unnecessary maintenance costs and railroad component damages that result in the suspension of railroad services. These technologies were first developed in advanced countries in Europe to support preventive maintenance, which meant that the railroad cars had to undergo inspections periodically. Note, however, that rolling stock maintenance technologies are now evolving to support predictive maintenance. Moreover, the demand for machine learning-based failure diagnosis technologies is increasing to simultaneously satisfy the need for greater reliability and lower maintenance costs to cope with faster systems, early works on the topic Choi et al. (2015) and Kim et al. (2011) found.

The Finnish transportation authority is currently building Europe's largest railroad recognition pilot system which includes a passive RFID solution designed to monitor all railroad cars in real-time. Europe is also strengthening the regulation on real-time railroad car monitoring, the detection of derailment, and the inspection of malfunctions. In Korea, an electric railway abnormality detection system has been installed on Seoul Metro Line 2 to monitor deterioration and vibration, and studies are being conducted on the development of a non-destructive diagnosis technology for key parts in the lower section of railroad cars, although they have yet to be commercialized, early works on the topic Korail (2014 & 2015) found.

The key features of the big data-based integrated data management system proposed in this study include the data compression and encryption/decryption function, which is designed to efficiently manage large quantities of sensed raw data, and the interface of the data with the maintenance support system. The maintenance support system is responsible for the ETL (Extraction, Transformation, Loading) and data preprocessing function after the data to be analyzed have been extracted from the integrated storage unit, the reporting of diagnosis and prognosis results, parts management for maintenance, and interface with the integrated DB, early works on the topic Byeon et al. (2004) and Kim & Cho (2002) found.

The remainder of this paper is organized as follows. First of all, Chapter 2 defines the function based on a use case of the maintenance support system and describes the design of the service model. Then, the design of the big data solution-based system architecture is described in Chapter 3, and the conclusion is presented in Chapter 4.

2. FEATURES OF ROLLING STROCK PART MAINTENANCE SUPPORT SYSTEM

This chapter describes the design of the service model of the railway part maintenance support system, which consists of fault diagnosis and remaining-useful-life prognosis technologies.

2.1. Definition of Maintenance Support Functions

Figure 1 shows the definition of the key functions from the viewpoint of the system user. The system is broadly divided into two parts: the first is the big data management system, which stores and manages the raw data sensed by the sensors installed at onboard and wayside, and the preprocessed data for fault diagnosis; and the second is the maintenance support system, which comprises a fault diagnosis module to determine actual faults based on the big data, and a remaining-useful-life prognosis module using a prognostics and health management (PHM) technology.

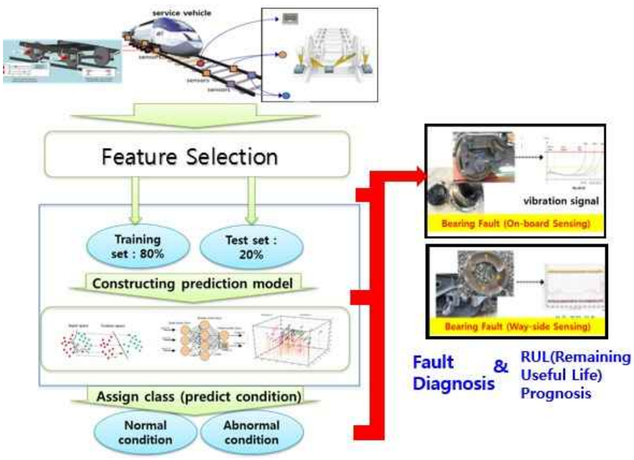

Figure 1. PHM-based maintenance support system

Figure 2(a) is the use case diagram for status data (preprocessed data) management from the user's viewpoint, and Figure 2(b) is the use case diagram of users of the maintenance support system.

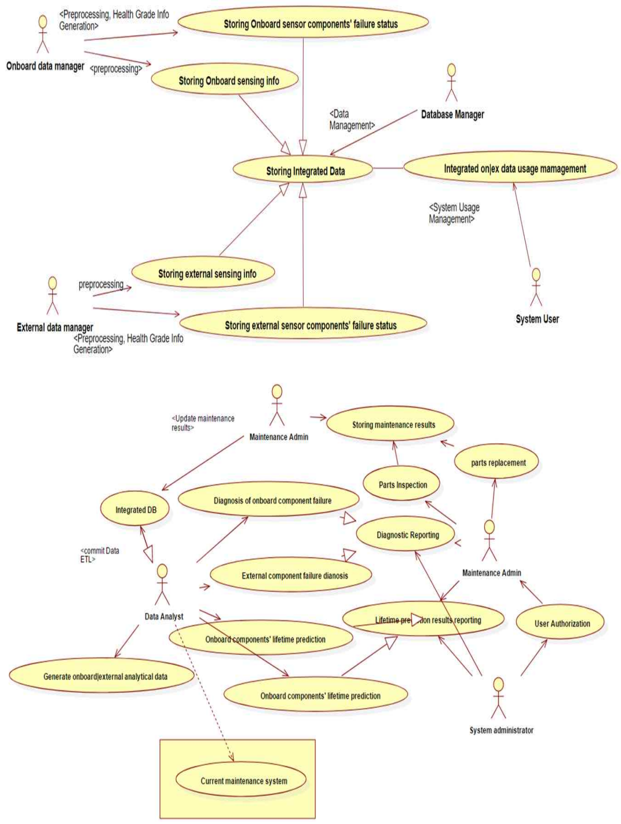

Figure 2. Use case diagrams of status data management (a: top) and the maintenance support system (b: bottom)

2.2. System Service Model

The service model of the status data management system and the maintenance support system analyzes the data measured by the composite sensors installed on the rapid transit railroad cars to monitor the status of car parts, and the sensors installed on the ground near the railroad tracks to monitor the status of the wheels and bearings of freight trains, and automatically calculates the fault diagnosis and the parts' remaining useful life.

Figure 3 is the flow chart of the service model. The system operation procedure is described as follows:

① Part vibration, temperature, current and other signals are measured in real time using sensors installed at onboard and wayside.

② Digital data are converted using DAQ.

③ Feature vectors are extracted and faults are diagnosed

④ Status data and diagnosis results are stored in a local DB.

⑤ Data are transferred from the local DB to the data storage unit of the big data analysis solution.

⑥ Data extraction is converted and loaded; feature vectors are extracted

⑦ Fault diagnosis and prediction of the remaining useful life of multiple cars are verified.

⑧ Results of the analysis are visualized and their reliability evaluated.

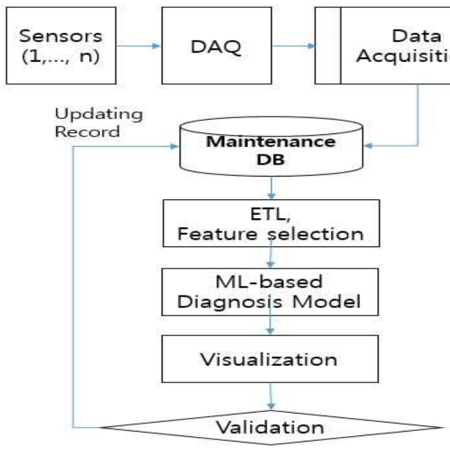

Figure 3. A flowchart summarizing individual steps for diagnosing bearing fault

Table 1 shows the functions of the status data management system and the maintenance support system.

Table 1. Functions of service model

Function	Description
Status Data Manage -ment	The status data must be operated in the big data analysis server to enable distributed and parallel processing.
	The data manager must have a user account management function.
	The sensor measure data stored at onboard and wayside local DB must be transferrable in real time.
	The fault status stored at onboard and wayside local DB must be immediately transferrable at the time of an event.
	The onboard and wayside data stored in the data management system must be interfaced to the maintenance support system in real time.
	The system log data are stored in the backup server in regular backup so that they can be recovered immediately during an emergency situation.
	The encryption and decryption of all data of the system must be provided.
	All of the data in the system must be decompressed for storage.
	Only the administrator can have the access and renewal privilege of all the data in the system.
	User accounts can be managed only with the administrator privilege.
	The system must provide the user log data.
	Data renewal by the system administrator must be synchronized in real time.
	Data measured by the sensors of the system must be downloadable for analysis.
	The system must provide a dashboard display function to monitor the time and key parts.
Mainte- nance Support	The maintenance support system provides the ETL function to analyze the data.
	The system provides a feature extraction function for fault diagnosis and remaining-useful-life prognosis.
	The system provides the classification model for the diagnosis of onboard and wayside part faults.
	The system provides a RUL prediction function for onboard and wayside parts.
	The system provides a function for reporting the results of part fault diagnosis and the results of RUL calculation.
	The system must provide the results of status data analysis to maintenance users.
	The system must provide the part maintenance UI to the maintenance users according to the results of the analysis.
	The system must provide a function that allows users to update the maintenance records in the integrated DB.

	The system administrators must be able to query the fault diagnosis and the remaining- useful-life prognosis.

3. DESIGN OF THE MAINTENANCE SUPPORT SYSTEM ARCHITECTURE

The design of the system architecture entails the process of analyzing the system architecture from different viewpoints to assist understanding of the system structure and to perform decision making from the architectural perspective. The system is located in the internal operation network of Korail, and the web server is configured to control access by external users. The S/W for key function development is composed of WAS (Web Application Server) to ensure the efficient maintenance and security of the system. All data communication networks are part of Korail's own private network.

3.1. Status Data Management System

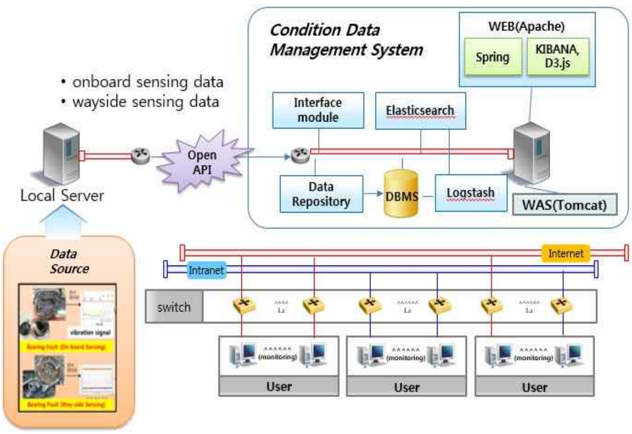

Figure 4. Architecture of status data management system

- User management by data manager

This function allows the creation and deletion of user accounts, the setting of user groups, and the granting of access privileges to user groups.

- Real-time collection of local DB data

This function collects the data measured by sensors stored at onboard and wayside databases.

- Real-time collection of fault diagnosis data

This function collects the real-time onboard and wayside fault diagnosis data.

- Maintenance of integrity of integrated DB

This function automatically creates an identifier to secure the uniqueness of the data and checks the key constraint condition.

- Data interface between systems

This function provides the interface for the stored data.

- Data backup

This function is responsible for the regular backup and recovery for replication of stored data.

- Data security and management

This function enables data encryption and decryption.

- Data management by administrator

This function enables the system administrator to search and query, and update, the data.

- Internal maintenance user management by administrator

This function allows the creation and deletion of maintenance user accounts, the setting of maintenance user groups, and the granting of system access privileges to user groups.

- Log data collection

The function automatically collects system log data and allows the administrators to search and query log data.

- Data query

This function creates the index of stored data, performs indexing for fast data search query (within 1 sec.), and outputs the statistical data.

3.2. Maintenance Support System

This section describes the modules of the maintenance support system corresponding to the WAS function in the logical architecture, as shown in Figure 5.

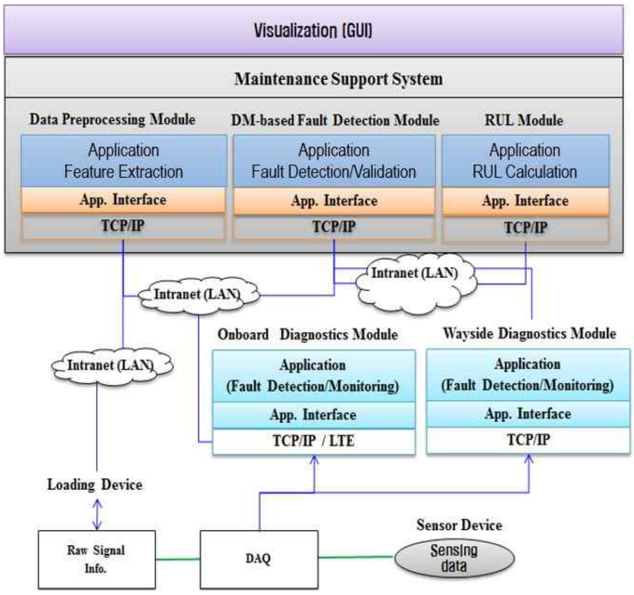

Figure 5. Architecture of maintenance support system

- Data preprocessing module

The module is responsible for data preprocessing and also provides a feature selection and extraction function that enables the creation of training and test data of the ETL and diagnosis of the accumulated status data.

- Fault detection module

This module consisting of a built-in data mining and machine learning engine utilizes training and test data for diagnosis model and determine and evaluate the actual diagnosis.

- RUL(Remaining Use Life) module

The module calculates the remaining useful life period of parts that correspond to a specific or higher class as the result of a diagnosis..

The logical architecture of the system includes a visualization module that provides the result information to the maintenance system decision makers.

4. CONCLUSION AND FUTURE WORK

This study designed the functions and architecture of the status data management system and the maintenance support system based on fault diagnosis and prognosis technologies in order to manage the key parts of Korail's railroad cars, with the goal of commercialization by 2020, in order to improve inefficiencies of existing maintenance. The system proposed in this study enables the big data analysis-based maintenance service to automatically detect (by sensors) the current status of a rolling stock, to evaluate any faults, to predict the remaining useful life, and to notify the maintenance staff of the results thereof.

Future areas of study include the acquisition of sensor-measured data of key parts, such as wheels, axis bearings, tripods and distribution panels, which are the targets of maintenance by Korail; the selection of an accurate fault diagnosis model by applying the optimal machine learning technique; and the development of software for prognosticating the remaining useful life of parts using the results of fault diagnosis.

ACKNOWLEDGEMENT

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BIOGRAPHIES

Hoon Jung received his BS degree in industrial engineering from Kyunghee University, Seoul, Rep. of Korea, in 1989 and his MS and PhD degrees in industrial engineering from Iowa State University, IA, USA and the University of Missouri, MO, USA, in 1997 and 2001, respectively. Since 2002, he has been working for the Electronics and Telecommunications Research Institute, Daejeon, Rep. of Korea, where he is now a senior researcher. His main research interests are supply chain management, logistics information systems, and PHM.

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